from the higher illuminated air masses and that diffraction can influence only the color of the light.

The color and the time of occurrence of the western purple light and of the afterglow are in agreement with all three classes of explanations. The relative rarity of the afterglow and its varying intensity with the position of the sun speak in favor of the idea of mirror reflection. It seems to me, however, that if the cause were mirror reflection from the sunset zone the light would appear somewhat less scattered and would give more light and shade effect in the mountains. As a matter of fact I have often wondered, as I stood in the mountains in the afterglow itself, at the shadowless or very weakly shadowing character of this peculiar flesh-red light; and how it often appears not merely as the western purple and the eastern afterglow but fills the whole intervening space with its all-pervading, mysterious, gloomy yellow-red. The breadth of the light-giving surface and of the mirror together are after all an inadequate explanation, it seems to me, for this diffuse behavior of the afterglow. Just as the sky is blue and the mountains and valleys are filled with blue haze during the day, so now the sky is purple, copper-colored, or reddish yellow and the mountains and valleys are filled with these colors. If reflection throws the western purple light into our eyes and upon the eastern mountains, then there must be a much stronger polarization of the purple.

If the sky's blue were a true fluorescence of the air, then the western purple light and the afterglow would be blue instead of red. I conclude, from their colors, that the sky's blue is merely a pseudo-fluorescence.

The peculiar form of a "salmon-colored spot" in which the western purple light often begins, has not yet been explained, while the arched form of the western purple seems to be a matter of course. Evidently we have not yet the last word in explanation of the western purple light and of the afterglow. In the case of the afterglow we may have to do with the combined effects of several factors. Nature is, indeed, always more complicated than we like to assume in thought. One thing is quite certain, *the afterglow on the eastern mountains and the eastern sky is* not a direct evening red, but *an indirect evening red which is brought down into the earth's shadow by mirroring or diffuse reflection and diffraction.* Put more simply: The afterglow in the east is the reflected splendor of the western purple light. We may therefore describe the afterglow also as an indirect alpenglow. Here also is repeated a relation similar to that of the first alpenglow: The west furnishes light and color, the east is illuminated thereby. Thus it comes about that light and color are stronger in the west than they are simultaneously in the east. If one stands on the eastern mountains and wholly in the afterglow, there appears no repetition of sunset in the west; one sees only a great surface of purple light spread over almost the whole western sky.

Here and there a sheaf of divergent rays [crepuscular rays] from a mountain or a cloud in the western sky, reaches high up into the recently empurpled heavens. (See Heim's fig. 18.) The shadow rays [or crepuscular rays] appear blue-green in the purple. Hence one may conclude that the air that appears to be already in the western purple, as we stand down below it, still receives direct rays from the sun at high levels above us. The western purple light therefore arises first from direct illumination of the upper air layers. Diffuse reflection and diffraction are but the processes that conduct the splendor down to our eyes in the earth's shadow or across to the mountains.

This does not enable one to decide, however, whether the purple light originates in the west behind the cloud or only on our side of the latter. If the former, then the clouds intercept the purple-colored solar rays; if the latter, then the purple does not develop where the cloud's shadow falls. The former appears to me much the more probable case.

The western purple light, then, seems to be the evening glow of the higher air directly illumined by the setting sun, reflected down into the earth's shadow to our eyes. The eastern afterglow shows us mountains and air indirectly illuminated by the reflection of this lofty evening glow.

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TWILIGHT PHENOMENA IN ARIZONA, SEPTEMBER TO DECEMBER, 1916.

By Prof. ANDREW ELLICOTT DOUGLASS.

[Dated: Department of Physics and Astronomy, University of Arizona, Tucson, Dec. 2, 1916.]

[In his letter transmitting this paper Professor Douglass corrects his statement, quoted by me in the REVIEW for August, 1916, 44:434, to the effect that red sunsets were not observed by him after the middle of September, 1916. His accompanying description of twilight colors is closely in accord with the classical description by von Bezold, which, together with Exner's classification of the twilight phenomenon will be found translated on pages 620 to 623 of this number of the REVIEW. Therefore, with the consent of Professor Douglass, I have inserted in brackets in his text the designation given by Exner to the phase of the twilight described. Thus, [(c) First twilight arch] is to be interpreted as meaning that the phase of twilight under consideration will be found under (c) of Exner's classification to have the designation here given.—*H. H. Kimball.*]

From September 16, 1916, to the present time the writer has watched every evening after sunset for the occurrence of bright twilight and afterglow colors, and shadow phenomena. The clearness of our atmosphere permits all these phenomena to be seen with greatest ease down to our horizon of mountains, which averages about one degree in elevation in all directions. From west-northwest to west-southwest the average height is about 1.8°, while in the northwest the apparent horizon descends a very slight amount below the true horizon. In the east the mountains rise from 1° to 2° above the true horizon.

On account of the clearness of the air the sun is never under any circumstances faint enough to be looked at directly by the naked eye. Clouds are rare and two levels of clouds still more rare, so that it becomes possible to estimate cloud heights by the time when direct sunlight ceases to illuminate them. It thus becomes possible here to use means of investigation that would seem incredible to an observer accustomed only to Atlantic coast conditions.

Out of 80 nights, clouds have interferred to a serious extent on only 6 nights. Slight cloudiness has prevailed on over 50 per cent of the nights. In fact, it is a condition of a few thin, scattered cirrus clouds that is most favorable to the beautiful ray phenomena so often noticed. [See Abbe's translations of Heim's and Bezold's descriptions of these crepuscular rays; this REVIEW, p. 622 and p. 625.]

As soon as the disk of the sun is behind the western mountain, a heavy bronze area [(b) Twilight glow] is apparent extending to a distance of 4° or 5° in all directions from the sun itself. At first this bronze is of a rather yellowish color, which soon changes to a reddish tone, lasting some 20 minutes after the disappearance of the sun.

After the sun has really set the clear western sky in that general vicinity shows a structure which seems likely to be due to a high layer of haze in the atmosphere. This structure usually appears as a faint, soft etching of large numbers of parallel lines. In general

these lines have a slight inclination from the horizontal, the northern ends being a little lower than the southern ends. The lines vary in size from a quarter of a degree in width and several degrees in length up to 1° by 10° or even larger. Near the horizon the size is always small, growing larger at the higher elevations. The conspicousness is very different on different nights and the view is always improved by good field glasses. A number of observations have been made on the motion of this detail, which in every case has been in a southerly or southwesterly direction, and a very rough analysis of the rate has given something in the neighborhood of 60 miles per hour. This structural effect, of course, exists in what otherwise appears to be an absolutely clear sky. It rises about 25° high in the west and may be traced through an azimuth of 60° or 75°. The passing of the colored sunlight across this structural detail, lower and lower towards the western mountains, was one of the first phenomena noted last September.

Five minutes after sunset the blue arch of earth shadow [(*a*) Dark segment] begins to rise above the eastern horizon with a brilliant pink curve [(*a*) First anti-twilight arch] of sunlit atmosphere immediately above it. If the night is favorable the pink arch is cut up into a large number of alternating blue and pink rays [see Abbe's translation of Heim's description, this issue of the REVIEW, p. 625] all pointing toward the spot opposite the sun. Twenty-three blue shadow rays have been counted at one time. Some of them may come from clouds visible above the western horizon and the blue shadow may be traced completely across the sky from western cloud to eastern arch. Often the shadow comes from clouds below the western horizon; but at this early moment in the evening, it can not usually be traced nearer the western horizon than 30°.

As the pink arch in the east [(*a*) First anti-twilight arch] rises higher and higher above the horizon, reaching an elevation of 8°, or 10°, or even 12° before it becomes too faint (on one occasion it seemed to appear at 18° elevation), the eastern [anticrepuscular] rays extend more and more toward the west, becoming fainter and fainter and very rarely showing directly overhead. As the pink arch in the east really disappears, 20 to 25 minutes after sunset, a pink glow begins to form in a great area extending from 10° or 15° up to 60° above the western horizon [(*d*) First purple light]. On perfectly clear nights this glow gradually settles toward the horizon [(*c*) First twilight arch] retaining for a long time between it and the horizon a deep lemon-yellow color [(*c*) First bright segment]. About 30 minutes after sunset the lemon-yellow has set [End of civil twilight] and for the next 10, 15, or even 20 minutes the pink glow is gradually disappearing below the western mountains.

When there are a few cirrus clouds at the proper distance to the west of us to cause shadows, the disappearance of the pink arch in the east [(*a*) First anti-twilight arch] with its [anticrepuscular] rays is immediately followed or even accompanied by the formation of a splendid series of bright [crepuscular] rays on the western sky. These are much brighter than those in the east and at first reach an elevation of 40° or more over the place of sunset and a length of 60° or 80°, if low, along the northwestern or southwestern horizon. The base of these rays at first may be 5° or 10° above the horizon, but as the half hour after sunset passes the rays extend from the visible horizon in a deep red color up to 10° or even 20° in altitude. As many as 22 of these bright rays, separated by as many blue shadows, have been counted at one time. A few of the very numerous measurements of elevation have been roughly worked out to get the elevation of the layer or curtain on which these rays and shadows are projected. The process is simple, for the length of time after sunset gives a rough idea of the hundreds of miles of distance between the observer and the clouds which are casting the shadows. This distance is easily shown to be 200 to 400 miles, for some of the best raylike shadows appear 30 minutes after sunset, at which moment the sun is setting at a point some 400 miles west of us. By carrying out this calculation it is easy to show that we are seeing shadows cast upon a layer about 12 miles above the surface of the earth.

As a rule, these shadows appear raylike in form, with the rays diverging from the sun (below the horizon). But occasionally rounded or elongated blue cloud shadows are observed, with direct sunlight, very deep red in color, which has passed underneath the cloud itself, and is projected higher in the western sky than the light which passes over the cloud. The color of these cloud shadows is usually blue but occasionally is a very striking green. [See Abbe's translation of Bezold, p. 622.]

When the pink afterglow [(*d*) First purple light] has sunk low in the west a faint pink glow suffuses the entire horizon [(*e*) Second anti-twilight]. As this second afterglow leaves the east it may be seen as a faint pink glow [(*g*) Second purple light] in the western sky at about an hour after sunset.

The most exquisitely beautiful combination of colors is obtained when there seems to be a long horizontal cloud shadow [(*c*) First twilight arch], cutting through [above] the western afterglow [(*c*) First bright segment] at about 25 minutes after sunset. Under such conditions the lemon-yellow area [(*c*) First bright segment] extends from the horizon perhaps 8° in height through a great part of the western sky, then comes a nearly complete interruption of shadow [(*c*) First twilight arch] above which is the most superb display of a brilliant red band [(*d*) First purple light] extending upwards perhaps 10° or more and divided into glowing [crepuscular] rays all pointing toward the sun, long since out of sight. The color of this pure red glow [(*d*) First purple light] is almost monochromatic and seems much like the color of prominences observed through the C line of hydrogen. It is so different in the splendor of its beauty from the pink edging to the afterglow seen on clear nights that it has become evident that special conditions are required to produce it at its best. And when seen at its best it forms one of the most remarkable meteorological displays ever witnessed by the writer.

TWILIGHT COLORS AT MOUNT WILSON, CAL., AUGUST-SEPTEMBER, 1916.

By WENDELL P. HOGE, Assistant Astronomer.

[Dated: Mount Wilson Solar Observatory, Cal., Nov. 1, 1916.]

[Mr. Ford A. Carpenter, Meteorologist, Weather Bureau, Los Angeles, Cal., transmits the following description of twilight colors observed at the Mount Wilson observatory, contributed by Mr. W. P. Hoge.]

In reference to red sunsets my "log book" contains the following note under date of August 4, 1916: "Very brilliant sunsets for several evenings." This indicates that these brilliant displays began about August 1. Their onset was rather sudden and they have slowly diminished in brightness, although they were quite marked during all of August. The effect is still very noticeable [November 1], particularly in the morning [when] I have a good sky line from 25 to 100 miles distant. The display is gradually growing fainter.